Exploring Nature's Fundamental Forces and Particles with the Large Hadron Collider

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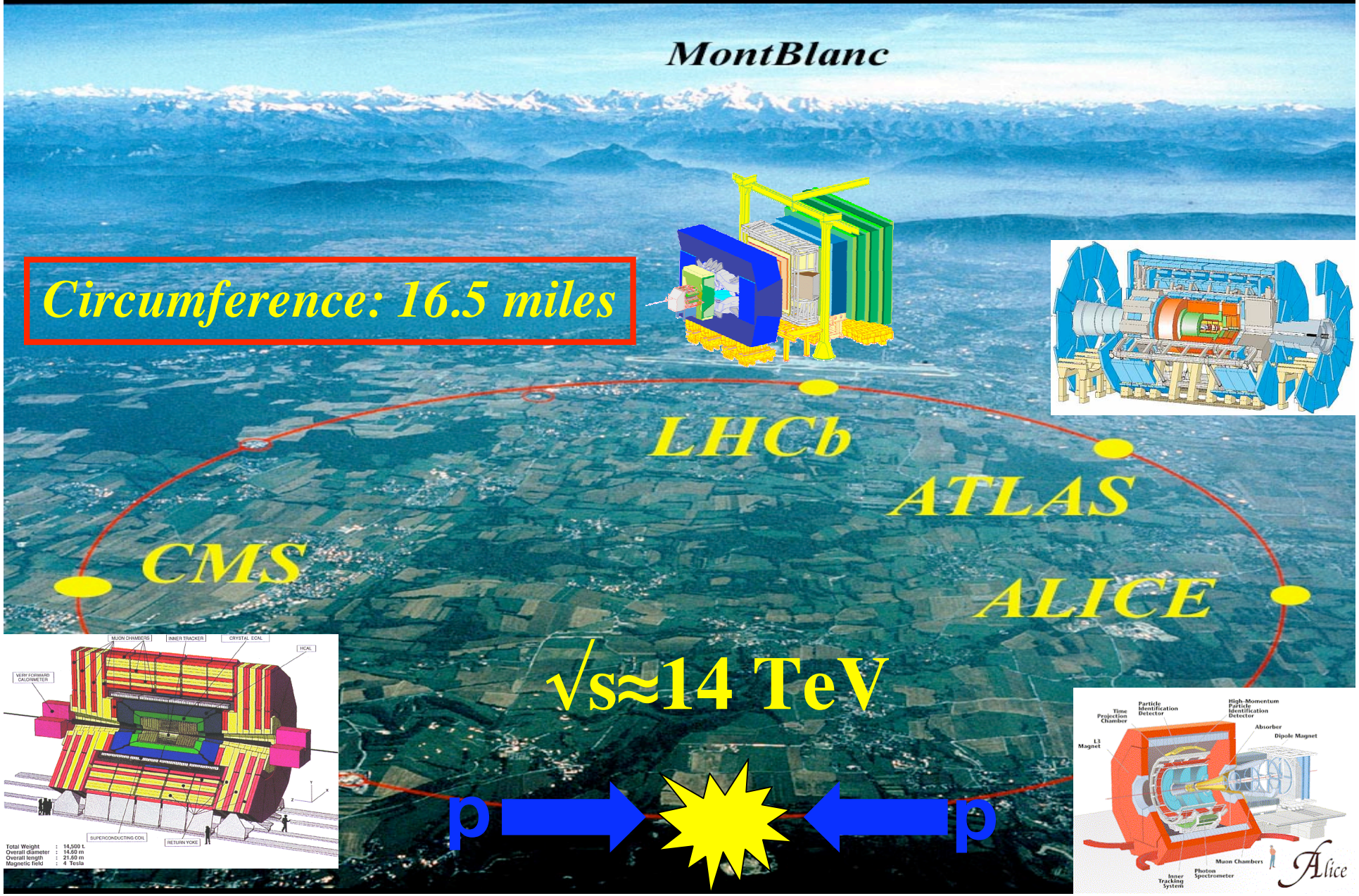
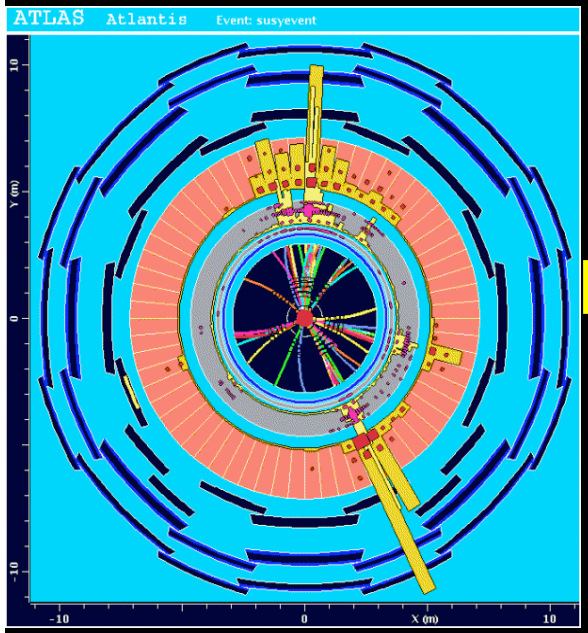
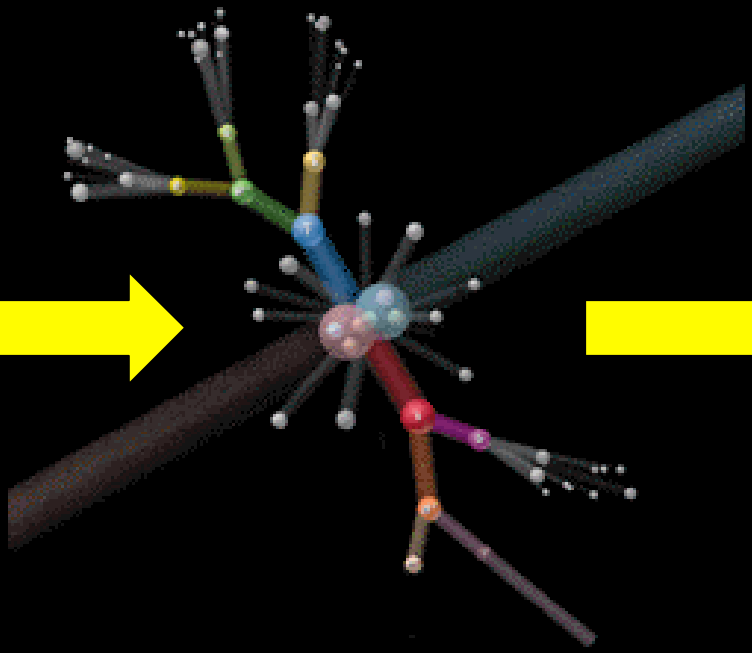
AAPT PHYSICS EDUCATION American Association of Physics Teachers

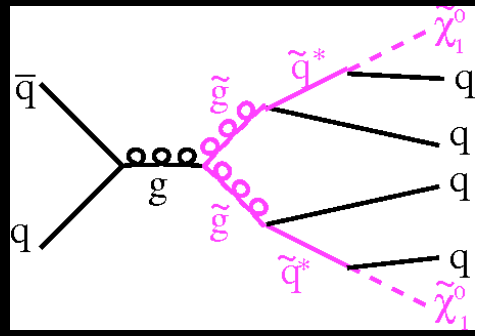
The Large Hadron Collider (LHC)



The Challenge



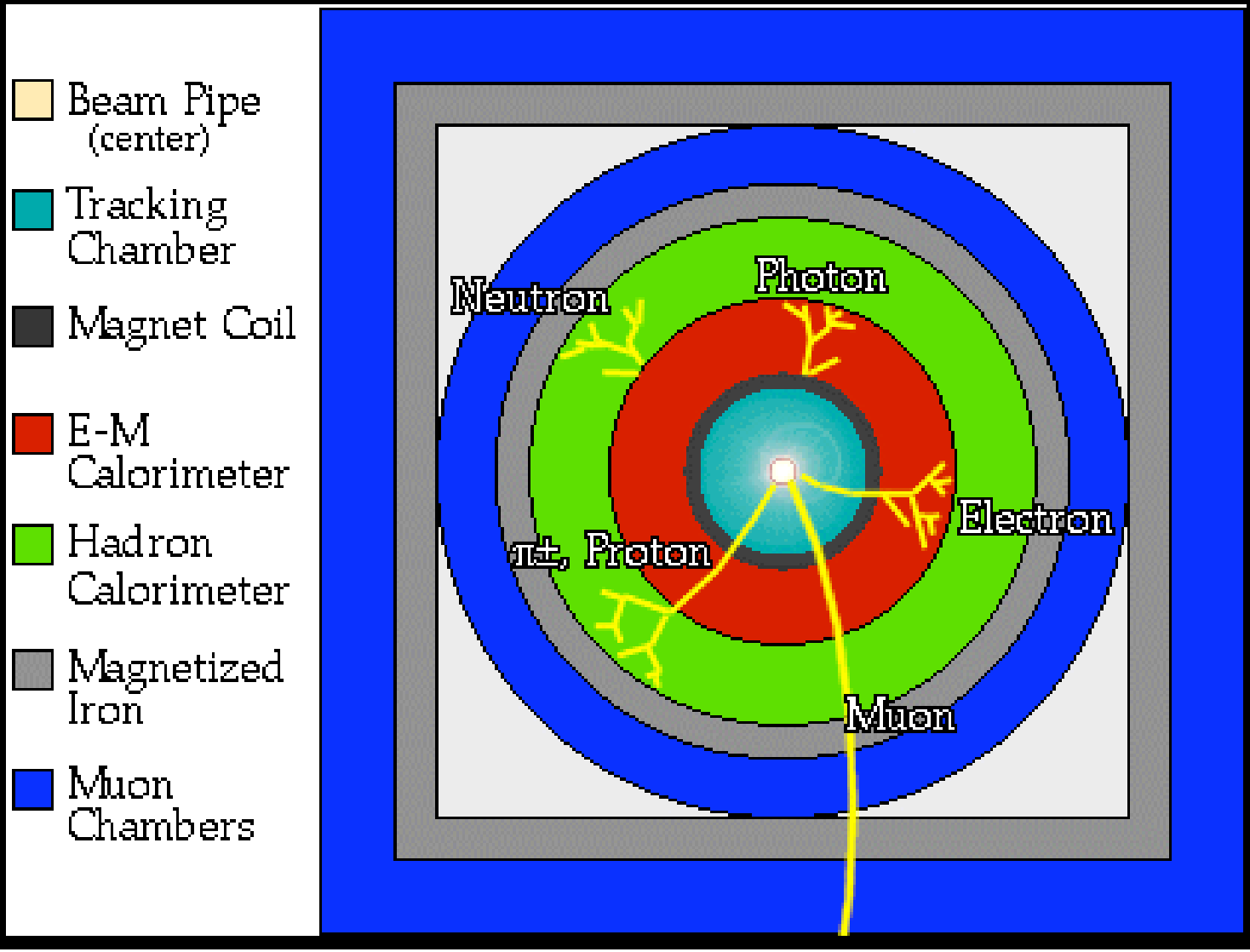




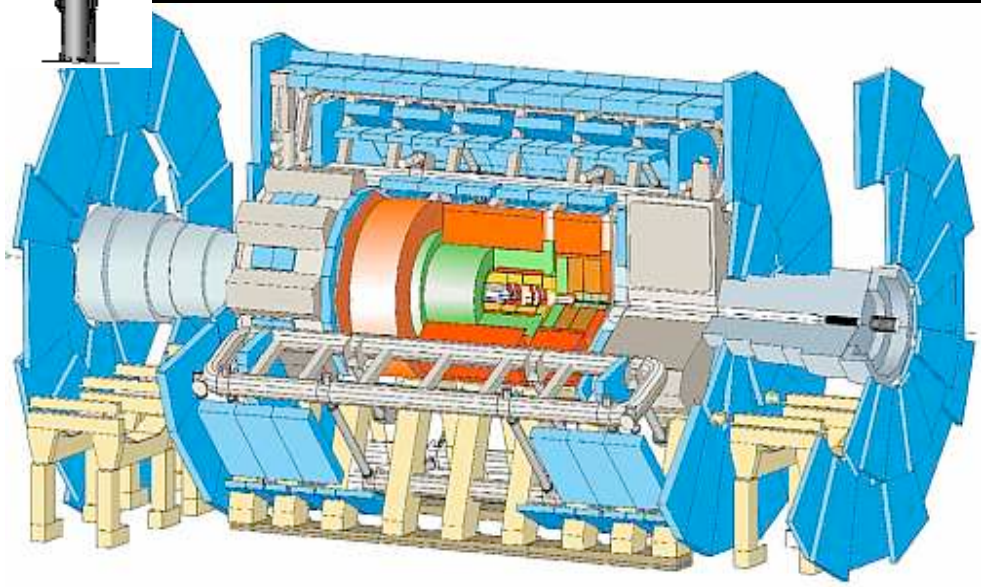
- Measured hits in detector
- => use hits to reconstruct particle paths and energies
- => understand the underlying physics

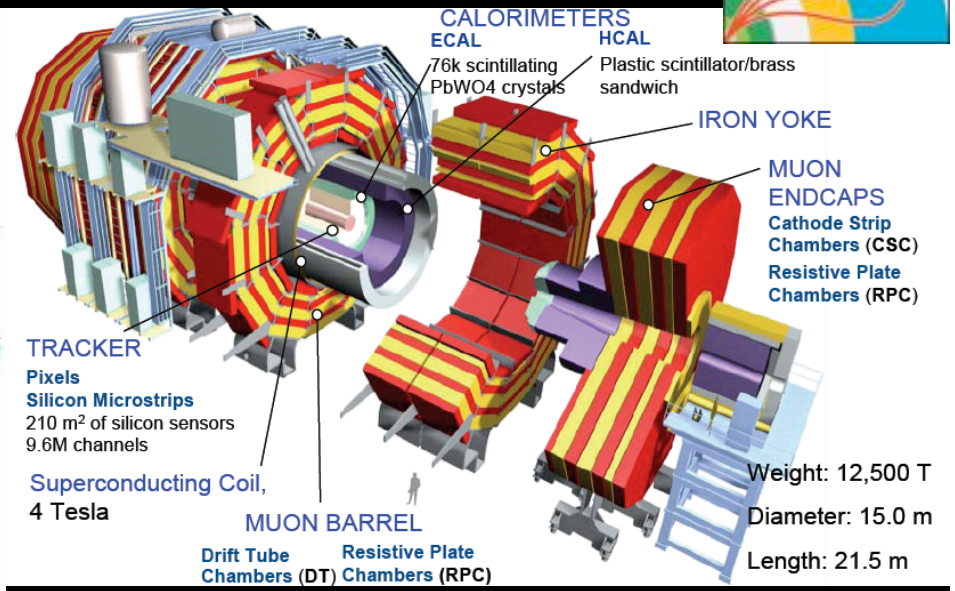
Particle Identification

- Detector designed to separate electrons, photons, muons, neutral and charged hadrons



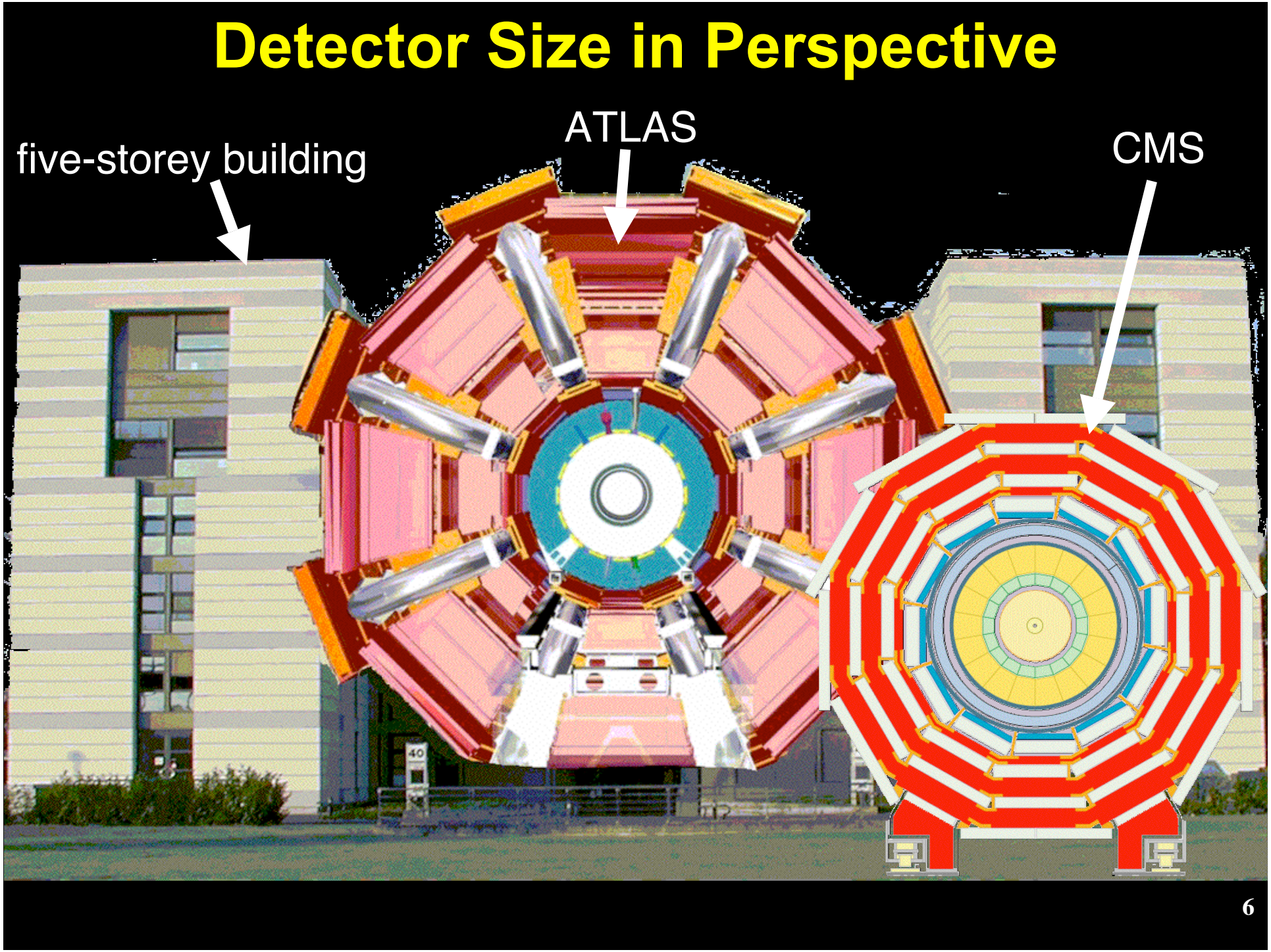
ATLAS and CMS Detectors



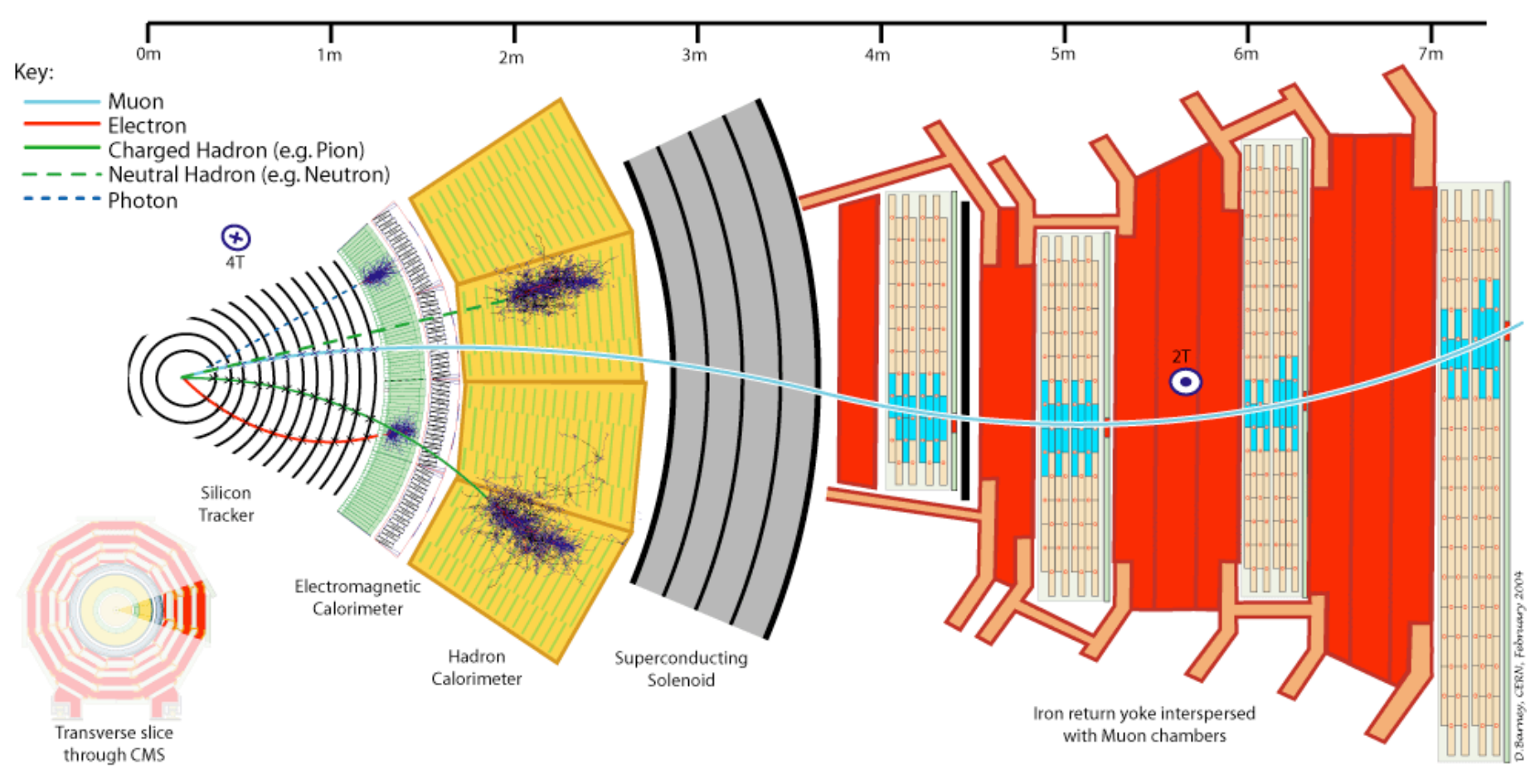


	Weight (tons)	Length (m)	Diameter (m)
ATLAS	7,000	42	22
CMS	12,500	21	15

Detector Size in Perspective



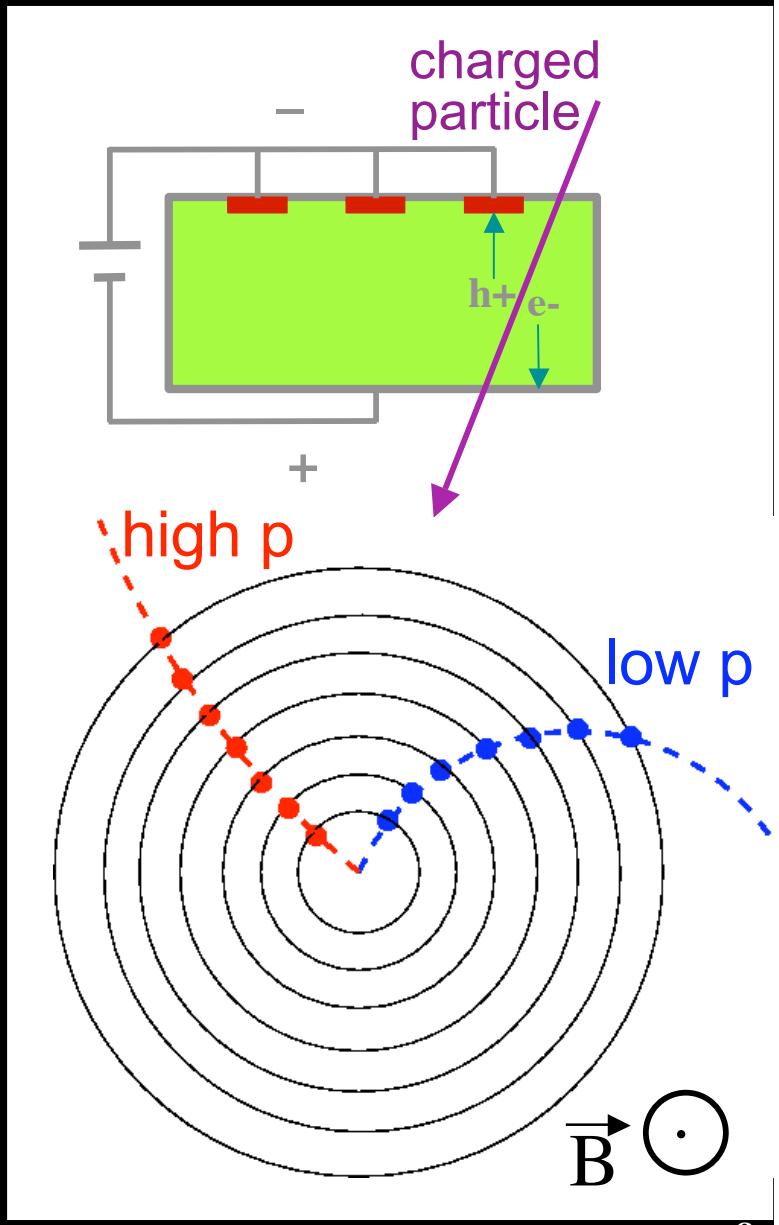
Detailed Layout



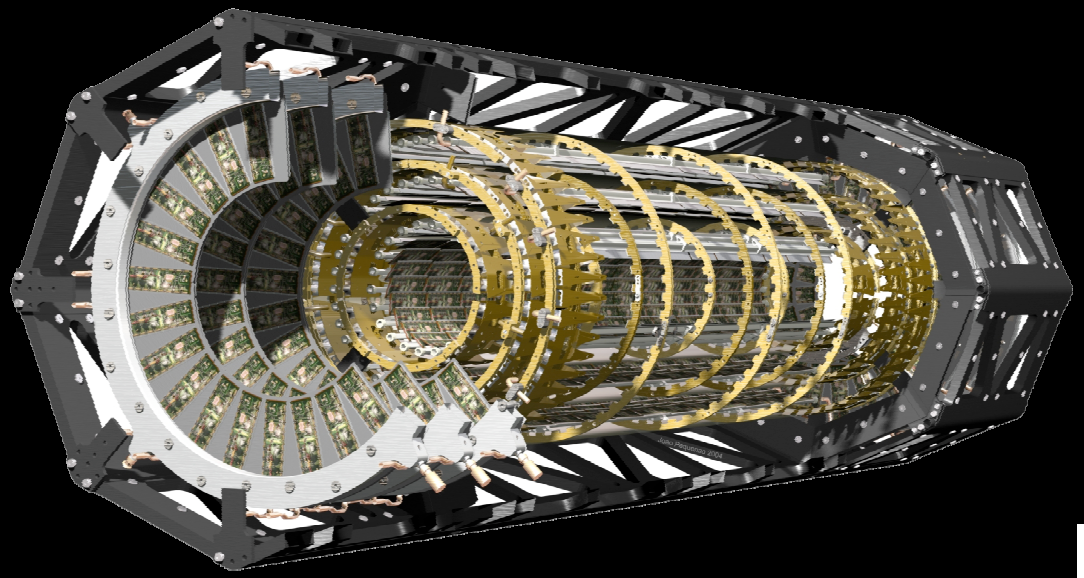
- About 100 million separate readout channels
  - 3000 km of cables

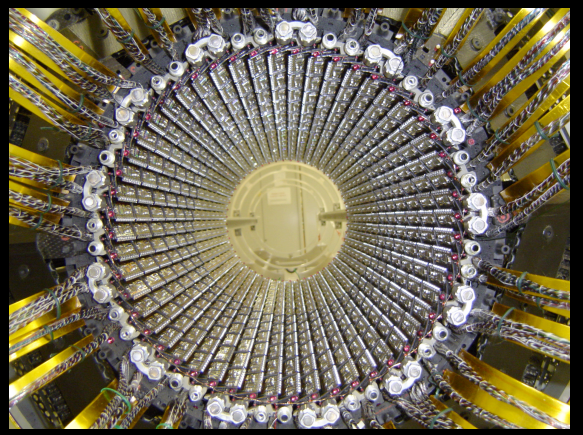
Silicon Tracking Detectors

- Charged particle traverses silicon sensor (semi-conductor)
  - Sets free charge carriers
    - Drift to electrodes
    - Measured charge gets collected at electrodes
  - Thus we find out position of particle
    - Resolution typically 15 μm
- Detector placed inside magnetic field:
  - Lorentz force: **F** = q **v** x **B**
- Hits along trajectory are fit to form a track
  - deviation from straight line proportional to momentum (**p**=m**v**)
  - Direction of curvature tells us the electric charge



The ATLAS Pixel Detector

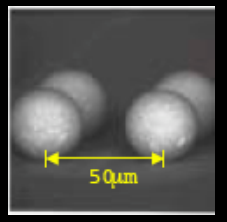




module

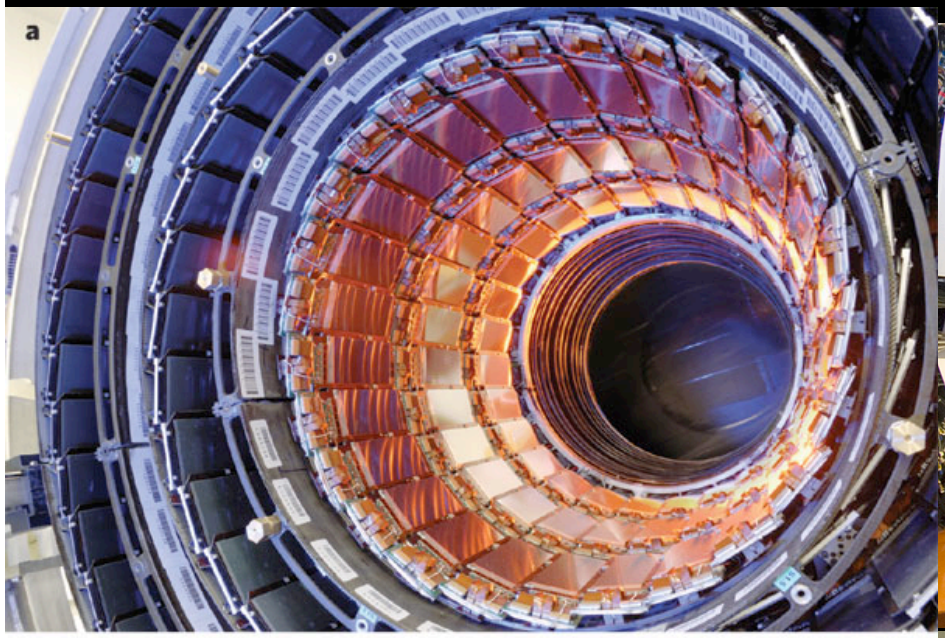
2 cm

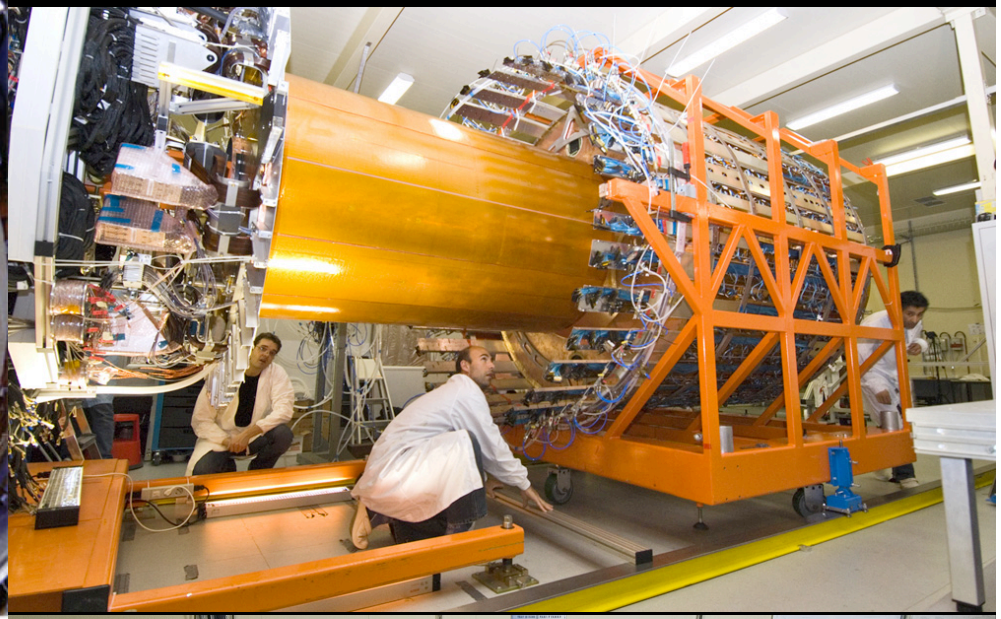
6 cm



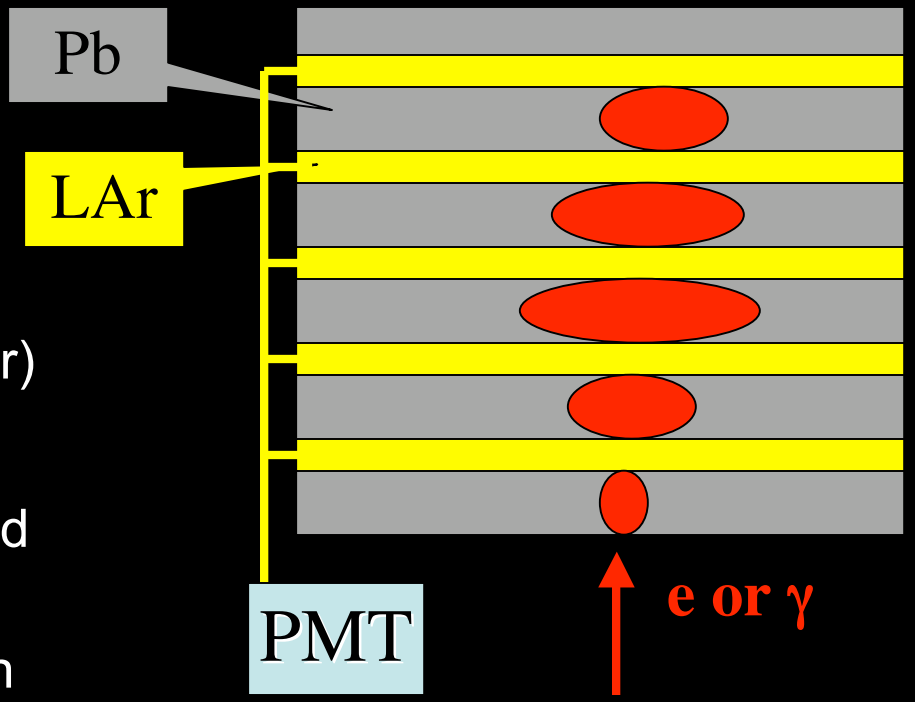
- Cylinder: L=1.4 m , R=12.25 cm
- 80,000,000 individual pixels arranged in modules:
  - 16 chips per module, 2880 pixels per chip => 46080 pixels/module
  - Distance between pixels: 50 μm (“pitch”)
- Designed and built mostly in the United States (Berkeley)

ATLAS Tracking Detectors



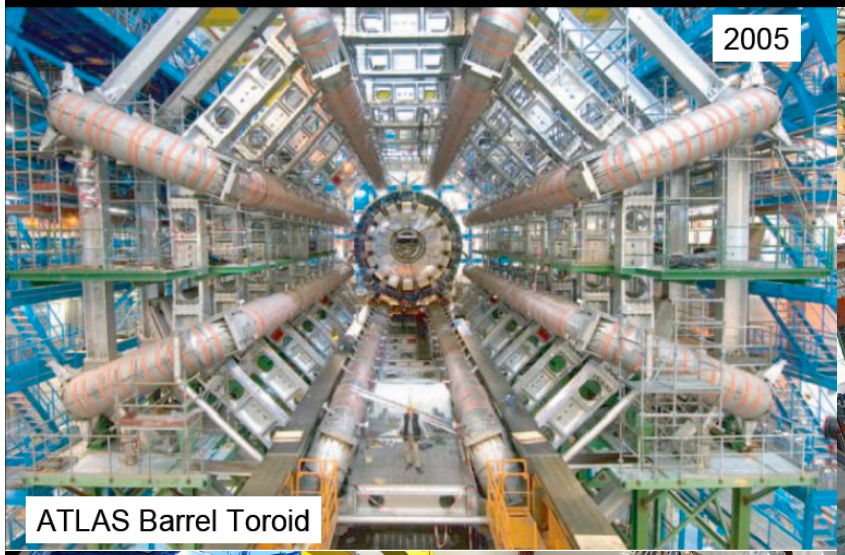


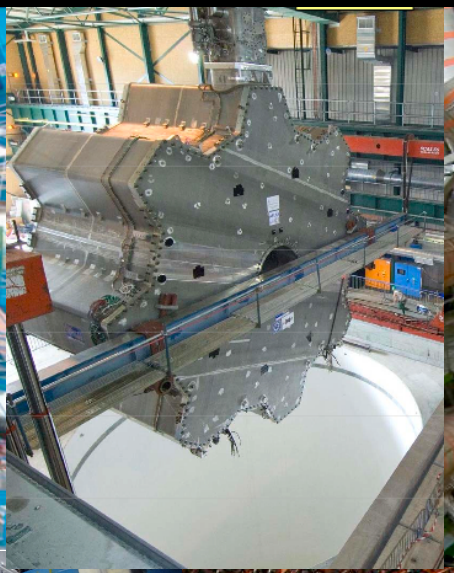
Electromagnetic Calorimeter

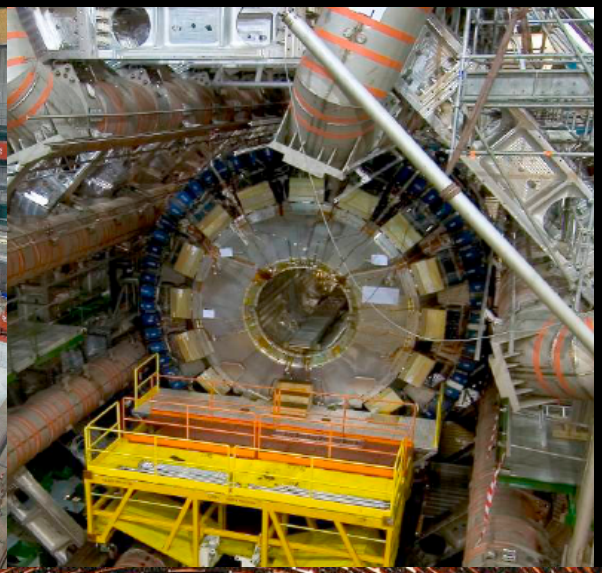


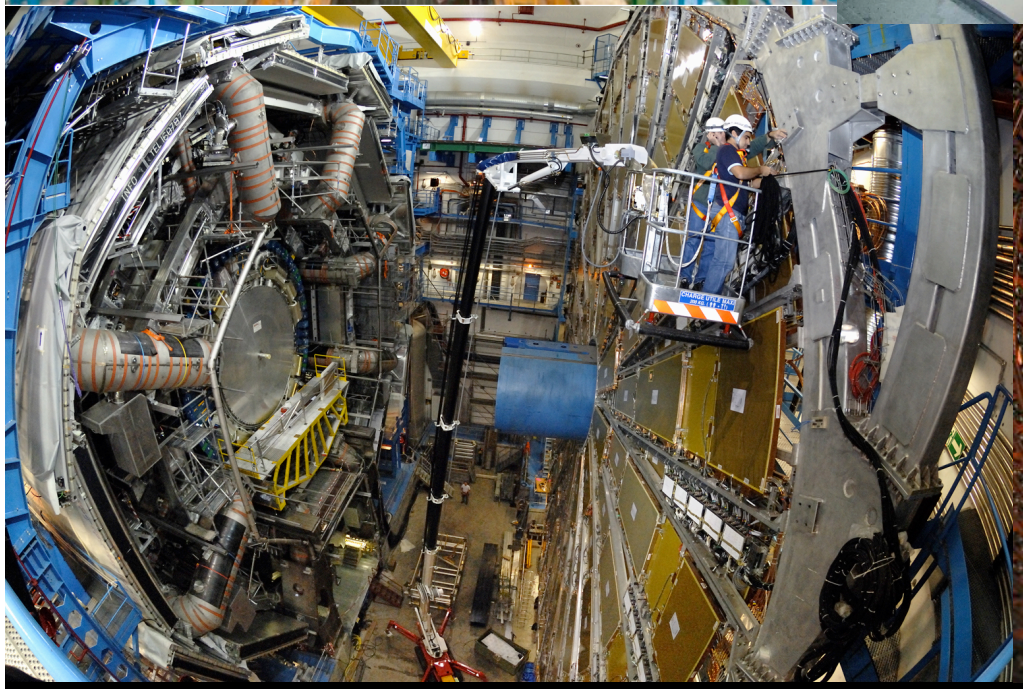
- Sandwich structure:
  - Absorber material: lead (Pb)
  - Active material: Liquid Argon (LAr)
- Energy measurement:
  - Electromagnetic shower produced through interactions with lead
  - Photons collected in Liquid Argon
  - N(photons)∝ energy of particle
  - Photomultiplier tube (“PMT”)
    - Amplification of signal => readout
- Position measurement:
  - High spatial granularity => position known

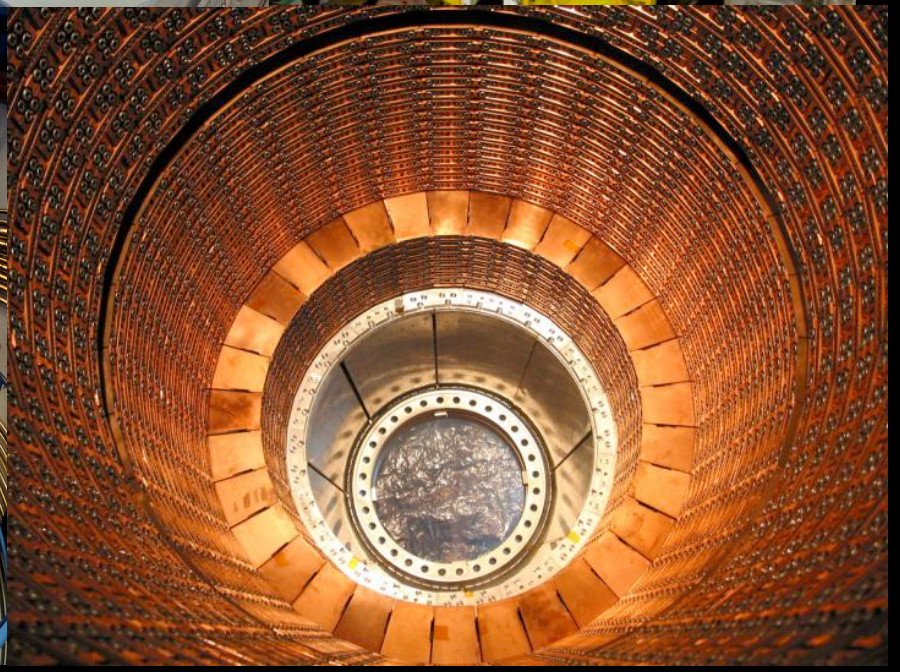
ATLAS Muon System and Calorimeters



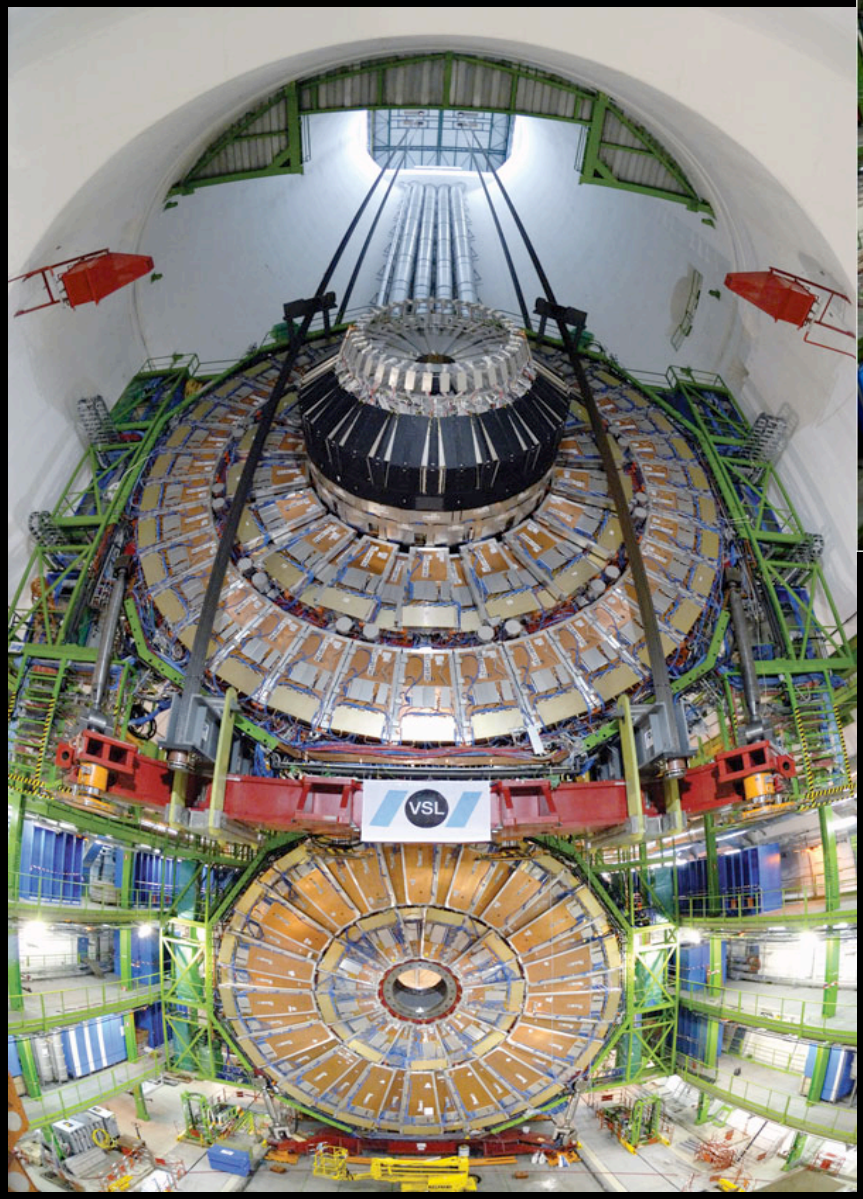


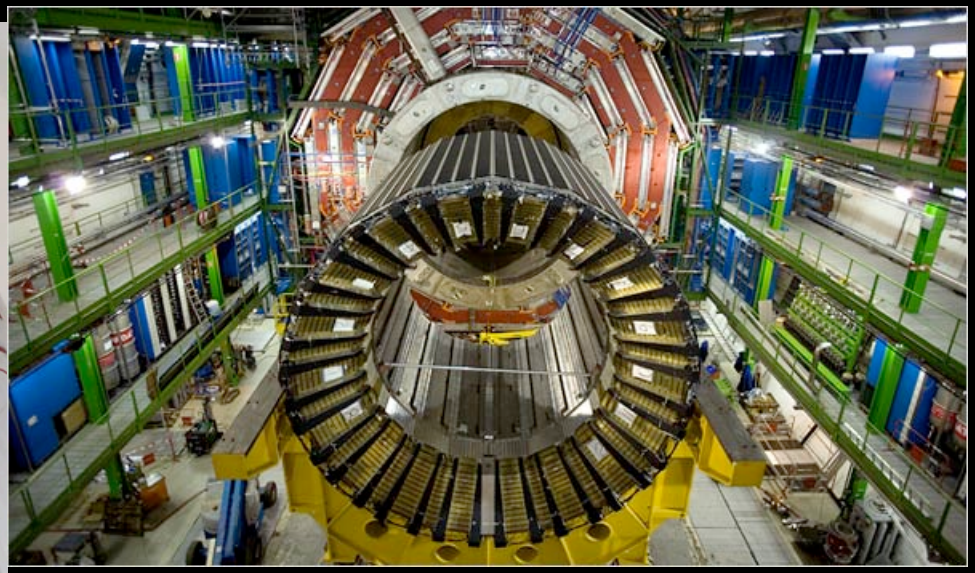




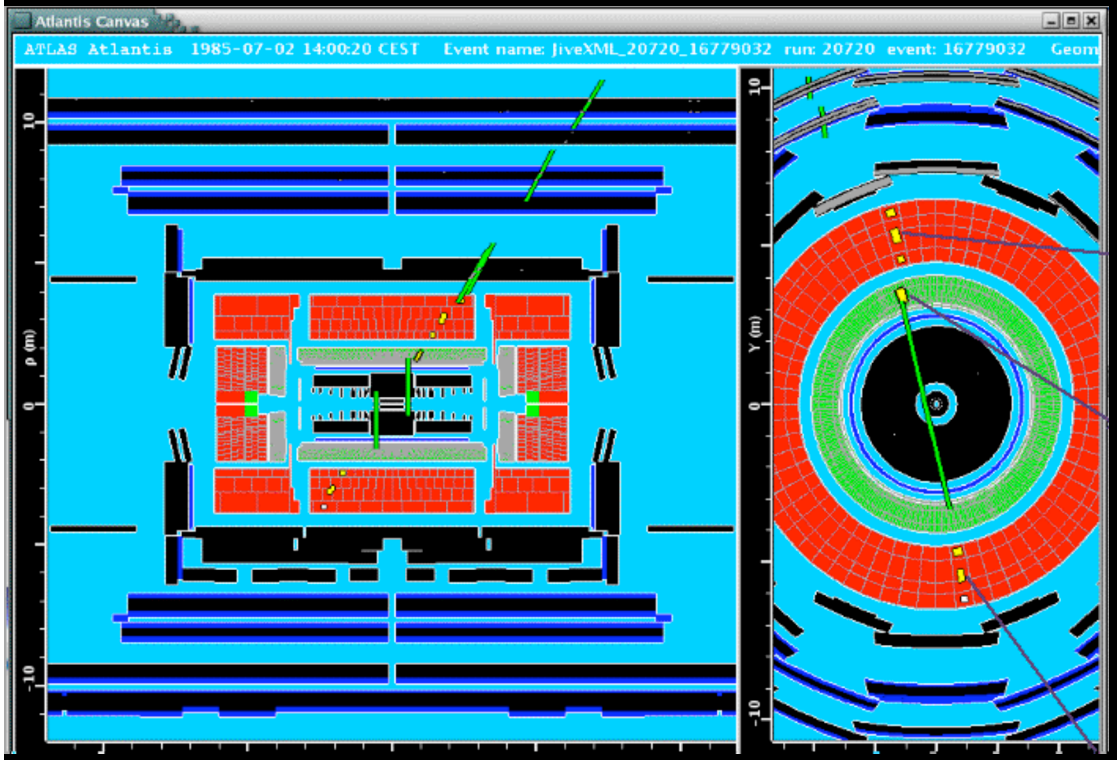


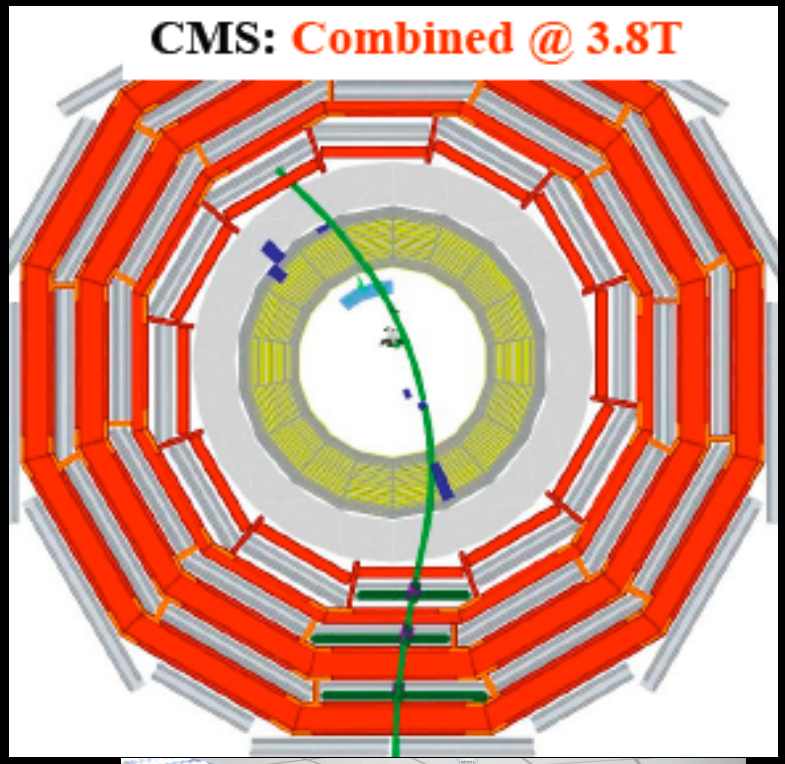
CMS





Cosmic Muon Data





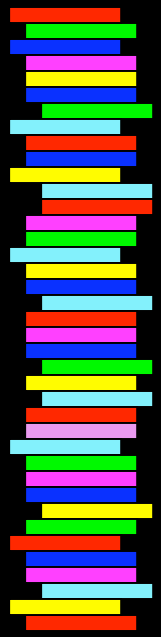
Experiments are currently preparing for LHC data taking
- analysis of cosmic muon data

2000 Physicists from all over the World

(including 400 PhD students)
+ many technician and engineers

Enormous Data Volumes

- **Pushing the computing limits!**
  - 1 second of LHC data: 1000 GigaBytes
    - **10,000 sets of the Encyclopedia Britannica**
  - 1 year of of LHC data: 10,000,000 GB
    - **25 km tower of CD's (~2 x earth diameter)**
  - 10 years of LHC data:
    - **All the words spoken by humankind since its appearance on earth**

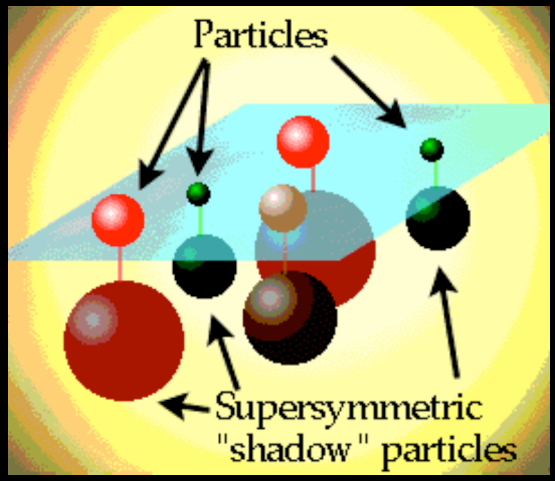


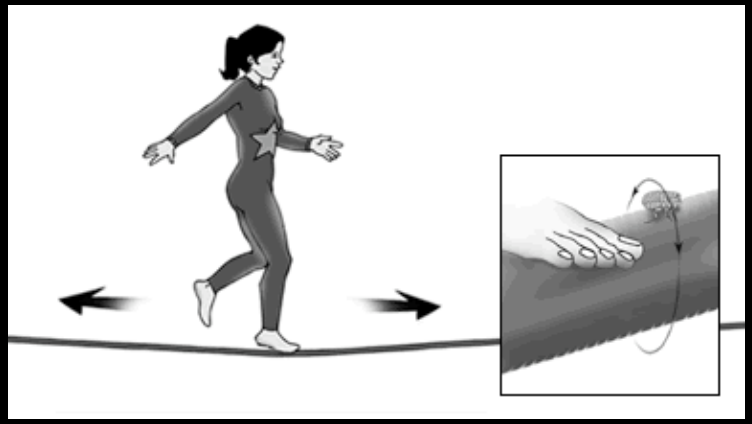
- **Solution: the "Grid"**
  - Global distribution of CPU power
    - More than 100 CPU farms worldwide share computing power

Three Example Analyses

Finding the Higgs Boson
-with photons
-with Z-bosons

Finding a Supersymmetric World



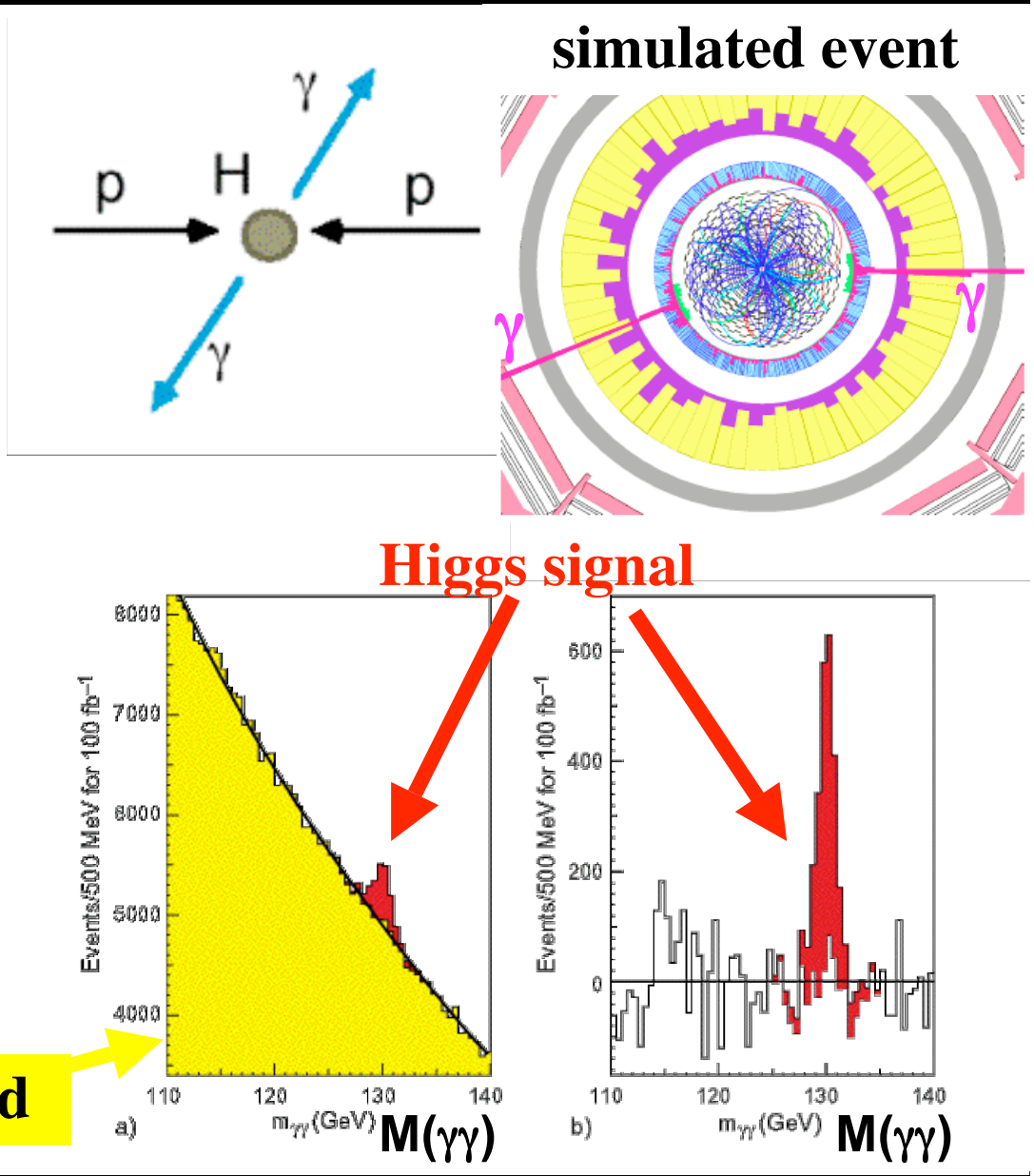


Finding more Spatial Dimensions

Finding the Higgs Boson (with photons)

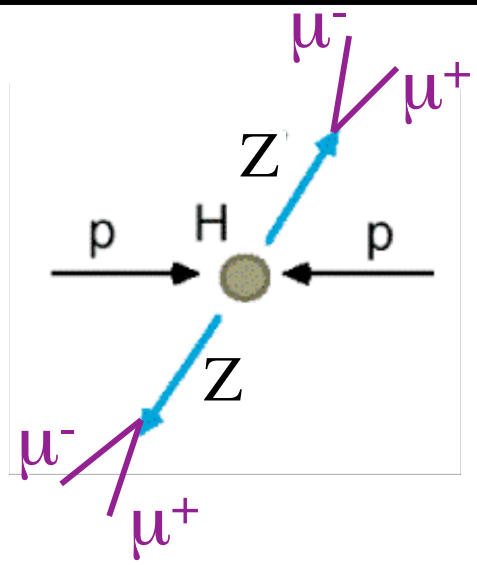
- Find 2 high energy photons
  - If M(H)<130 GeV/c^2
- Separate signal from backgrounds
  - Backgrounds can look exactly the same
  - but for γ's from Higgs:

$$M(H)=M(\gamma\gamma)=\sqrt{[(E_1+E_2)^2-(p_1+p_2)^2]}$$

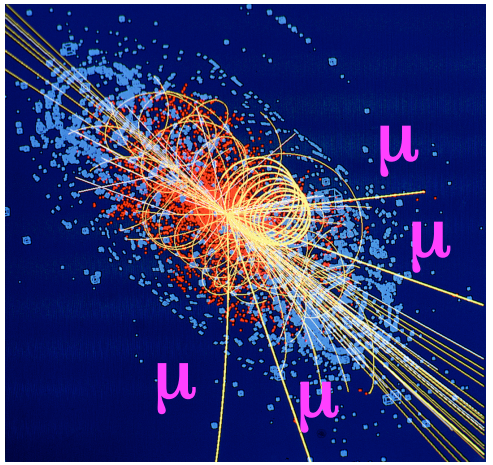


Finding the Higgs Boson (with Z's)

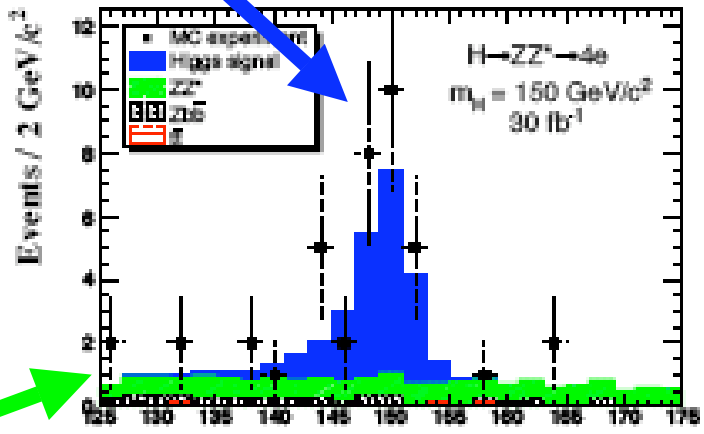
- Find 4 high energy muons or electrons
  - If M(H)>130 GeV/c^2
- Separate signal from backgrounds
  - Again calculating the invariant mass
  - Backgrounds much smaller than in diphoton case:
    - Easier!



simulated event

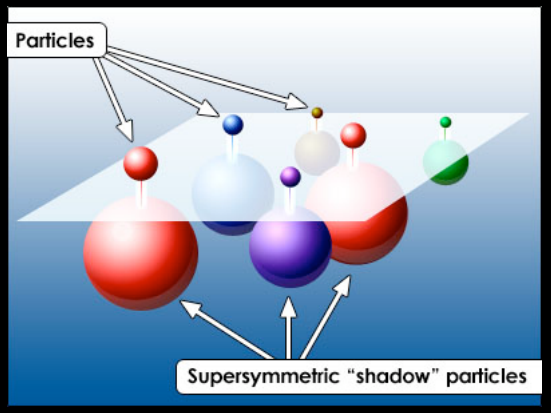


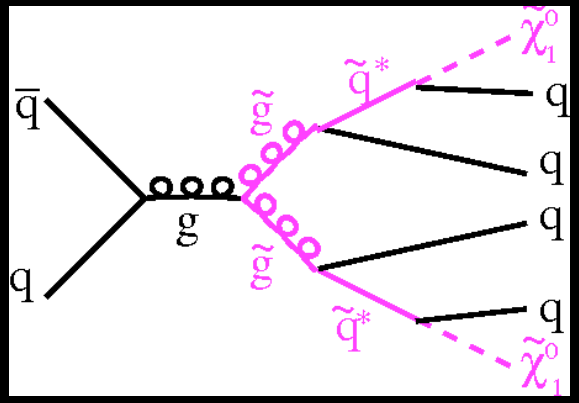
Higgs signal

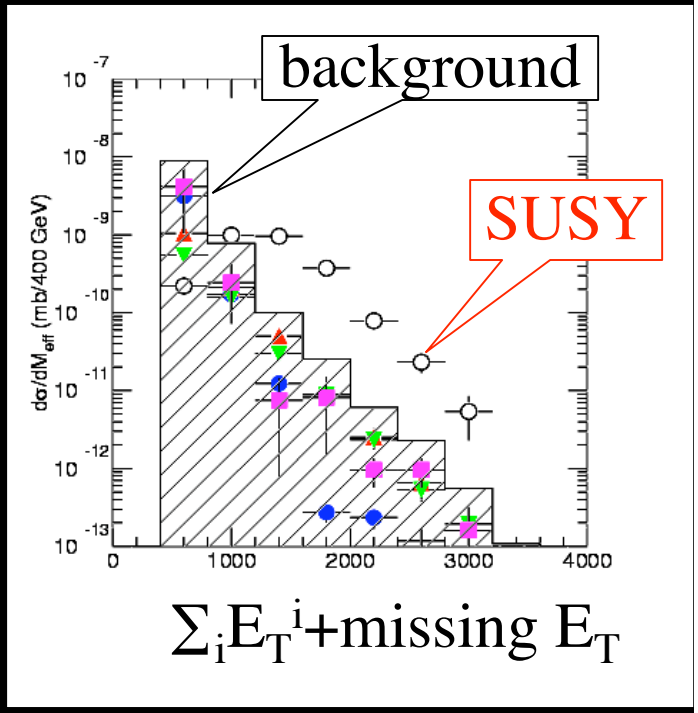


Background

Finding a Supersymmetric World





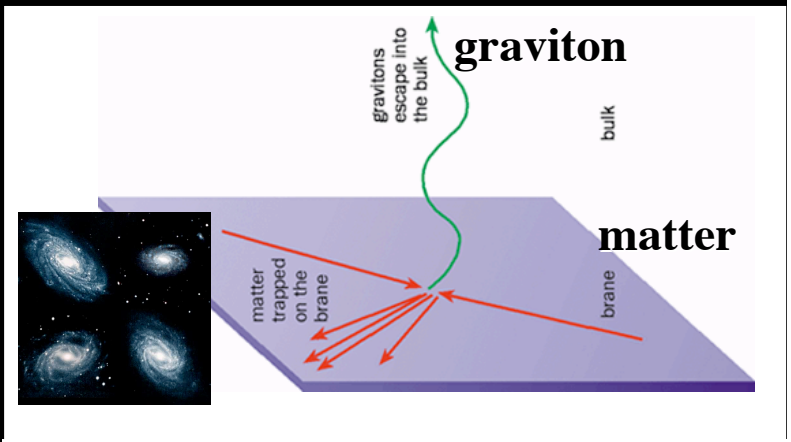


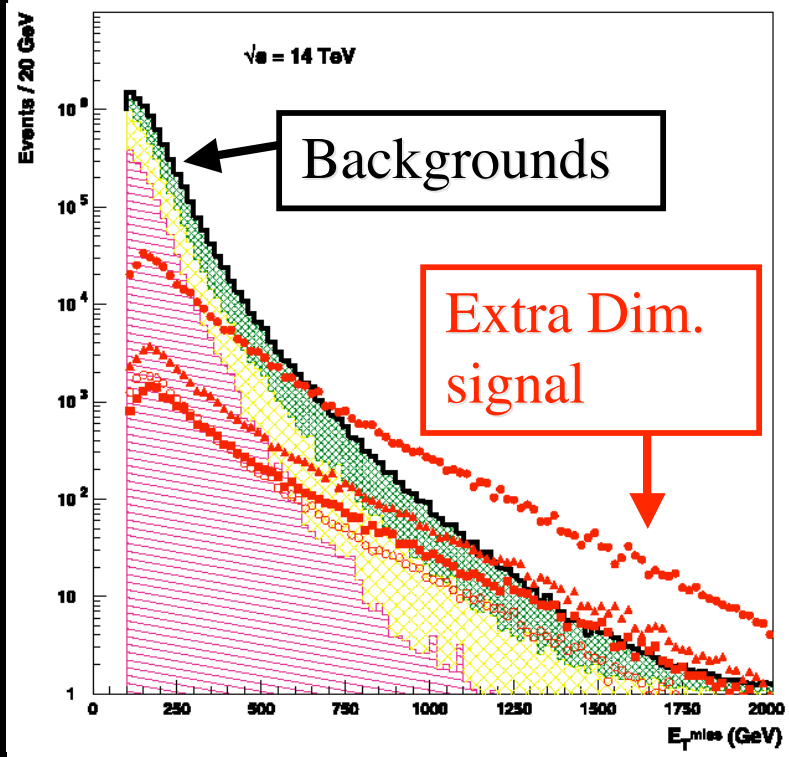
- **Supersymmetric particles decay into ordinary particles:**
  - Measure decay products
  - Dark matter particle ($\tilde{\chi}_1^0$) escapes detector unseen:
    - Momentum balance tell us presence of dark matter particles ("missing E_T")
- **Search strategy:**
  - Search for many high energy particles plus large missing E_T

Might find the missing Dark Matter in the Universe

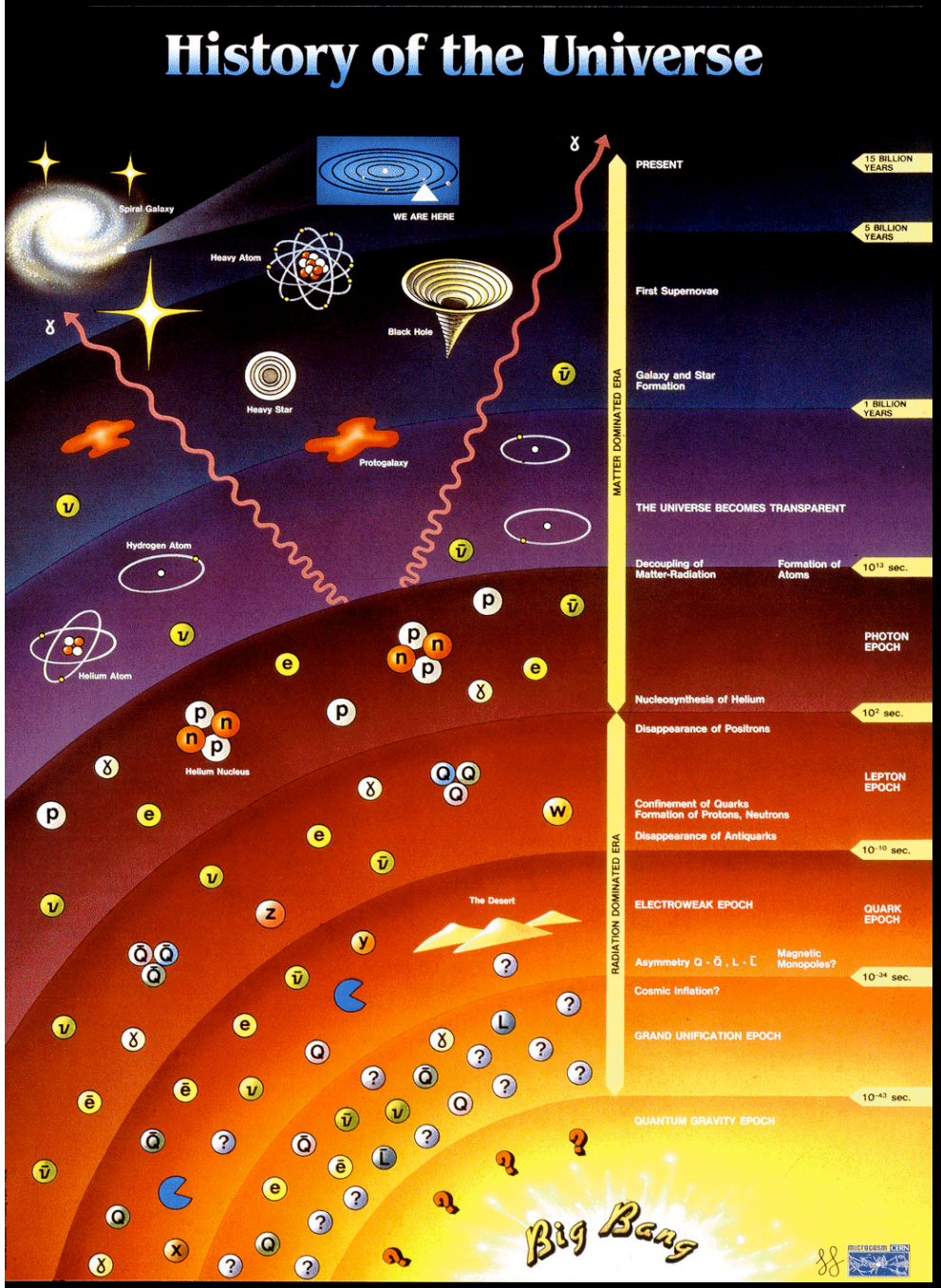
Finding more Spatial Dimensions

- We live in a 4D world
  - Gravity also lives in our world
- Gravity might also live in extra dimensions:
  - Kaluza-Klein Gravitons can be produced at LHC and then escape into extra dimensions
  - We cannot see the ED's since they are tiny and curled up
- Escaping "graviton" causes momentum imbalance
  - pp $\rightarrow G_{KK}$+X (≈ "nothing" +X)
  - Detect "nothing" experimentally: "missing energy"



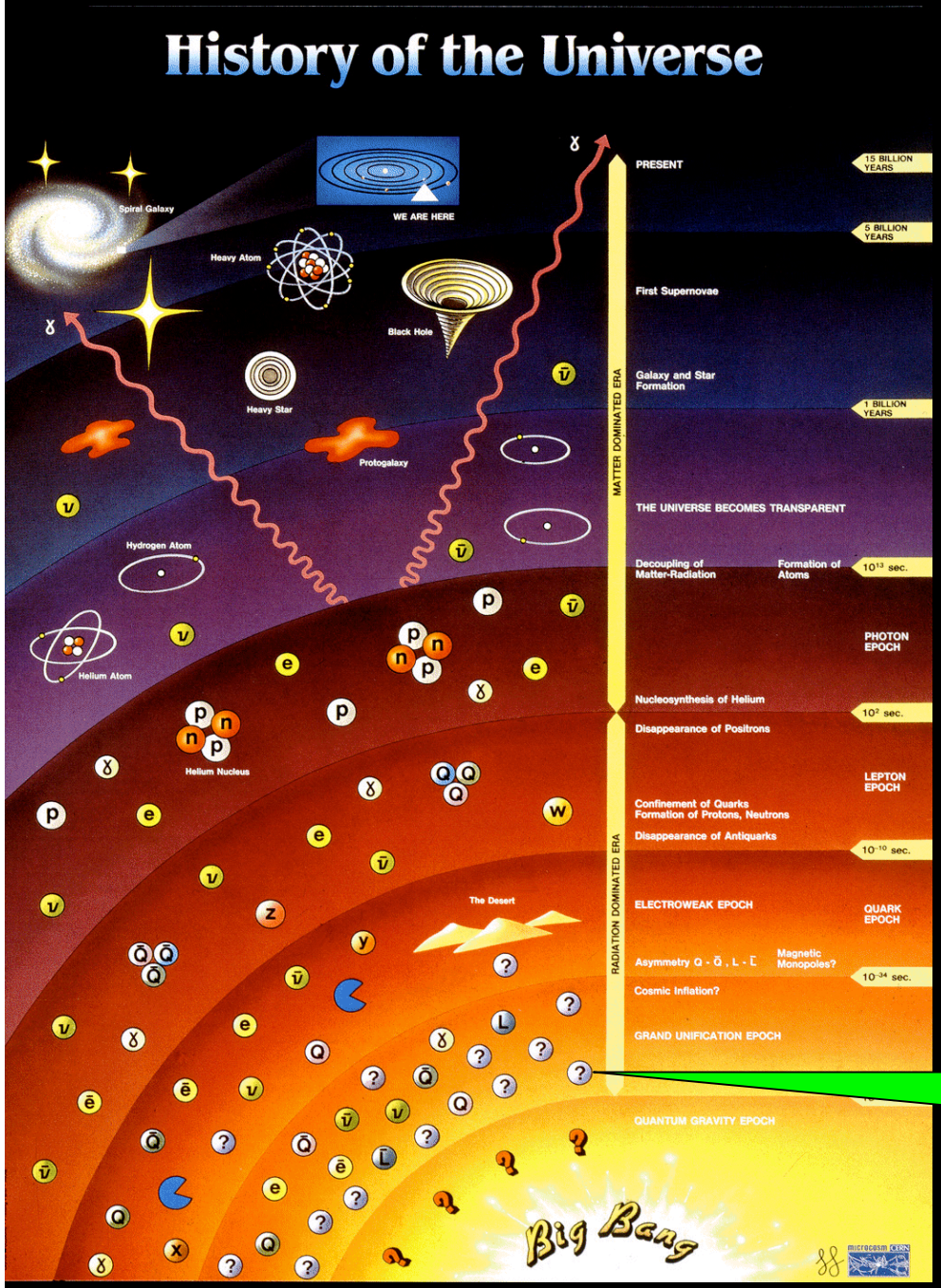


Momentum imbalance



Conclusions

- After a 20 year design and construction phase the LHC experiments are taking data!
  - Cosmic muons now
  - pp collisions later this year
- 2000 physicists collaborate on each experiment towards a common goal
  - Unraveling the physics of the fundamental building blocks of matter



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Will we find those ?'s

Further Information

- CERN: http://public.web.cern.ch
- Particle Physics: http://particleadventure.org
- Experiments:
  - ATLAS: http://www.atlas.ch
  - CMS: http://cmsinfo.cern.ch/outreach/

  (including many movies)

And talks tomorrow in Session DHH:

- Peter J. Limon: *the LHC Accelerator*
- Ayana T. Holloway Arce: *the ATLAS Experiment*